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Evapotranspiration Rates from Bermudagrass and Corn at Raleigh, North Carolina[1]

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SYNOPSIS. Evapotranspiration of bermudagrass and corn were measured with lysimeters at Raleigh, N. C., over 3 growing seasons. The Penman formula in three modifications accounts reasonably well for the observed values. Roughly, evapotranspiration was equivalent to 0.8 of net radiation over the crop.

KNOWLEDGE concerning short-term evapotranspiration rates of common field crops in the southeastern United States is still scarce. In 1956 a series of studies was begun to provide such data at Raleigh, North Carolina and, in particular, to test the idea that evapotranspiration rates could be predicted from weather data. If such tests were encouraging, one could, with confidence, predict the evapotranspiration rates at locations and times other than those where the actual observations were made.

PROCEDURES

Measurements of maximum evapotranspiration rates were made in 1956, 1957, and 1958 with 3 different types of percolation lysimeters in general form described by Gilbert and Van Bavel.[3] For all three types, evapotranspiration for a measurement period was considered to be equal to the amount of water added minus the amount of water recovered as percolate. For the 1956 and 1957 data it was assumed that the soil equilibrated to the same moisture content following the recharge application of water at the end of each period of measurement. During the 1958 growing season measurements of the soil moisture content were made with a neutron probe and a correction was made to compensate for any differences in the soil moisture content at the beginning and ending of a measurement period.

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[3] M. J. Gilbert and C. H. M. van Bavel, "A simple field installation for measuring maximum evapotranspiration." Trans. Am. Geoph. Un. 35:937–943. 1954.

Lysimeters

Two types of lysimeters were planted to bermudagrass in all 3 years. The first type, referred to as the "barrel" type, consisted of a common oil barrel (diameter 56 cm., height 78 cm.) installed with the top rim 5 cm. above the soil surface.

A soil support platform was installed in each barrel 15 cm. above the bottom. A 5-cm.-diameter aluminum access tube was inserted through the center of the support platform and then 58 cm. of soil was added. This brought the soil surface up to 5 cm. below the upper rim. The soil was Norfolk fine sandy loam which had a moisture storage capacity of 10% by volume between pressure potentials of about —0.1 and —1.0 bar. The amount of percolate was measured with a simple electric probe accurate to 0.3 mm. Three barrel-type lysimeters were installed.

The second type, used in the bermudagrass study, was a square tank, 100 × 100 cm. and 91 cm. deep. A tilted concrete floor was installed in the bottom of the tank which caused all percolate to flow to a small cylindrical depression in one corner of the tank. The percolate was pumped from this collection point to a remote measuring station through 8-mm. ID polyethylene tubing. The reproducibility of the recovery system was 50 cm.,^{3} equivalent to .05 mm. of water depth.

This second or "square" type evapotranspirometer had a soil support platform 18 cm. above the bottom. Approximately 68 cm. of soil was placed on this platform which brought the surface up to 5 cm. below the upper edge of the tank. In 1956 and 1957, 1.5 to 3.0 mm. granite rock screenings were used as the growing medium for the bermudagrass. The moisture holding capacity of the screenings was approximately 4% by volume or 2.5 cm. of water for the entire soil column. The screenings were replaced by Norfolk fine sandy loam in 1958.

A third type of evapotranspirometer was planted to corn in 1957 and 1958. Three units were used during 1957 and 6 units were used during 1958. These tanks were identical to the "square" tanks in bermudagrass except for two aspects. They were 92 cm. square and the percolate was collected at a remote location by gravity flow. Norfolk fine sandy loam was used in all these tanks and the precision of measurement was about 0.05 mm. of water.

Location and Management

Bermudagrass cover—The bermudagrass area used for this study was 30 m. long and 24 m. wide. Three sides of this area were surrounded by fields covered with grass. The north side was partially sheltered by a tool shed which was about 10 m. from the area.

The barrels were recharged on an average of once every sixth day with a minimum of 4 cm. of water. This amount would be any combination of rainfall and sprinkle irrigation. All irrigations were applied to the tanks after sunset after which the surrounding area was sprinkled for 3 hours at a rate of about 1 cm. per hour, the tanks being covered during the latter operation.

The grass over the entire area was clipped to a height of 5 cm. on an average of once every fourth day. Average growth was about 3 cm. and this material was removed from the experimental area. The area was clipped at any convenient time during a day; however, the lysimeters were generally clipped after 1600 hours.

The square tanks received applications of approximately 1.2 cm. of a complete nutrient solution each evening during the 1956 and 1957 growing seasons. After the rock screenings were replaced by soil, the tanks were treated in the same manner as the barrels.

Corn cover—The corn studies were conducted on a plot 40 m. by 30 m. The plot was located 100 m. west of the bermudagrass area and was entirely surrounded by sod. Corn was planted in rows, 92 cm. apart: sweet corn in 1957 and field corn in 1958.

The soil moisture was recharged on an average of once every sixth day. When irrigation was required, water was added to the tanks and then the surrounding field was furrow irrigated. This method was used so that no shelters would be required to cover the lysimeters.

Weather Data

Six types of observations were made during the measurement periods. Rainfall, wind at 2 m., air temperature and relative humidity at 2 m. in a shelter were recorded with standard Weather Bureau instruments. Net radiation, as measured by Beckman and Whitley net radiometers, was measured 1.5 m. above the bermudagrass and 4.6 m. above the soil surface on the corn area. The corn reached a maximum height of 3.4 m., so the radiometer was never less than 1.2 m. above the crop. Hours of sunshine were recorded with a Campbell-Stokes sunshine recorder.

Estimates of Evapotranspiration

Three methods for predicting evapotranspiration rates were used. The first method shall be referred to as the Penman Formula.[4] This calculation requires four climatological observations—relative humidity, air temperature, wind, and net radiation. In our case, net radiation was measured rather than estimated from sunshine duration and no reduction factor was employed in the formula.

The second method shall be referred to as the "0.8 × H" method, which is based on the assumption that, on the average, 0.8 of the net radiation energy is used for evaporation. This assumption reduces the calculation of evapotranspiration to a one-step multiplication. All calculations reported are based on the heat of fusion of 590 calories for water at 10° C. The 0.8 figure is based on the average Bowen ratio implied by the Penman formula when applied to average weather data at Raleigh, N. C. This estimate varies with the time of the year. It also depends upon location, but not much, as similar calculations for other Southeastern locations show.

The third estimate of potential evapotranspiration was by the "Penman Nomogram" method.[5] This calculation requires measurement of air temperature and percentage of possible sunshine as well as values for extraterrestrial radiation. The latter values are a function of the time of the year and latitude and must be obtained for each location. The method is an attempt to reduce the complexity of the original Penman formula without undue sacrifice of accuracy.

RESULTS

A comprehensive schedule of the periods of observation and the lysimeters used is given in Table 1.

The data collected for the bermudagrass are shown in Table 2 as evapotranspiration amounts for 51 periods extending over 3 growing seasons, a total of 298 days, or an average of 6 days per period. The table also shows the computed amounts for the same 51 periods. These amounts were obtained by applying the formula to each day of record and summing the result for the period involved. No estimate of evapotranspiration by the Penman Nomogram was available for the 1956 season for lack of sunshine duration data. No data are available before July 21, 1956, because the grass cover was not considered complete until that date.

The data for the three seasons are also illustrated in Figure 1 in which evapotranspiration is expressed as the accumulated amount beginning with the first day of observation.

Data obtained with corn are shown in Table 3 as evapotranspiration amounts for 22 periods extending over 2 growing seasons. The data represent a total of 133 days, or an average of 6 days per period. In 1957, sweet corn

Table 1—Lysimeters and periods of observation used.

Crop	Lysimeters (Number)	Period
Bermudagrass	Barrels (3) - Square (2)	7/21/56 - 9/29/56
Bermudagrass	Barrels (3) - Square (2)	6/18/57 - 9/20/57
Bermudagrass	Barrels (3) - Square (2)	5/30/58 - 9/22/58
Sweet corn	Square (3)	6/5 /57 - 7/25/57
Field corn	Square (6)	6/9 /58 - 9/22/58

Table 2—Maximum evapotranspiration from bermudagrass for 51 periods during 3 growing seasons as measured by 2 methods and estimated by 3 theoretical methods.

Period			Evapotranspiration, mm.				
			Measured		Theoretical		
No.	Start	Duration, days	Barrels	Square	Penman Formula	0.8 × H	Penman Nomogram
1	7/21/56	5	24.1	13.2	25.9	22.9	-
2	7/26/56	4	8.9	22.1	19.3	16.3	-
3	7/30/56	9	33.3	33.8	44.2	39.4	-
4	8/8 /56	5	20.3	19.8	27.2	24.4	-
5	8/13/56	3	12.7	12.7	15.5	13.7	-
6	8/16/56	6	17.5	21.1	22.6	19.3	-
7	8/22/56	4	13.7	12.7	14.7	12.2	-
8	8/26/56	3	7.4	10.2	12.4	11.2	-
9	8/29/56	3	18.0	13.7	15.5	13.5	-
10	9/1 /56	2	6.6	8.9	8.6	7.6	-
11	9/3 /56	2	6.6	6.9	5.8	6.9	-
12	9/5 /56	3	4.1	9.1	7.9	7.1	-
13	9/8 /56	6	17.0	19.6	23.9	20.3	-
14	9/14/56	3	11.7	12.4	14.0	10.7	-
15	9/17/56	7	26.9	23.9	27.2	21.3	-
16	9/24/56	5	4.3	7.9	4.6	2.8	-
17	9/29/56	5	9.7	16.8	14.7	13.0	-
Total for season		75	242.8	264.8	304.0	262.6	-
18	6/18/57	3	11.9	23.1	16.0	14.2	13.2
19	6/21/57	9	33.8	42.4	48.3	41.9	36.8
20	6/30/57	5	25.9	29.5	30.7	25.7	24.4
21	7/5 /57	6	34.8	37.8	42.4	32.8	30.5
22	7/11/57	6	30.2	33.5	35.8	30.2	29.0
23	7/17/57	7	33.8	34.5	41.4	34.3	30.2
24	7/24/57	6	31.0	23.6	29.0	25.9	23.9
25	7/30/57	5	11.9	24.4	29.0	24.1	23.1
26	8/4 /57	7	22.4	33.0	38.1	31.0	29.0
27	8/11/57	5	25.7	23.1	22.6	18.3	16.0
28	8/16/57	4	13.0	6.1	12.4	8.9	8.1
29	8/20/57	7	17.0	28.4	26.9	22.9	18.8
30	8/27/57	8	31.5	30.0	35.3	29.2	35.3
31	9/4 /57	7	17.0	15.0	15.7	13.7	10.2
32	9/11/57	9	18.3	20.8	29.5	25.7	23.4
33	9/20/57	6	18.3	15.7	21.1	18.0	18.0
Total for season		100	376.5	420.9	474.2	396.8	369.9
34	5/30/58	8	27.2	37.1	50.0	47.0	34.0
35	6/7 /58	10	40.6	41.9	72.6	59.7	52.3
36	6/17/58	7	27.2	23.1	27.2	30.7	23.1
37	6/24/58	4	11.4	14.7	20.3	19.3	16.3
38	6/28/58	6	26.9	24.9	41.4	38.1	35.1
39	7/4 /58	3	14.2	14.2	15.5	14.2	10.9
40	7/7 /58	4	12.2	14.2	21.6	20.1	14.5
41	7/11/58	5	19.8	22.4	26.9	25.4	17.0
42	7/16/58	7	26.9	27.2	40.9	38.1	29.7
43	7/23/58	8	23.6	41.9	53.3	46.7	43.7
44	7/31/58	11	42.4	18.5	60.7	53.8	45.7
45	8/11/58	4	25.7	29.2	19.3	16.3	15.0
46	8/15/58	14	35.1	37.6	59.9	53.1	45.5
47	8/29/58	6	22.1	24.1	32.5	27.9	28.4
48	9/4 /58	5	23.6	17.8	26.7	22.6	22.6
49	9/9 /58	7	23.1	20.6	29.5	25.1	25.7
50	9/16/58	6	15.7	16.8	21.6	17.5	19.0
51	9/22/58	8	24.9	31.8	33.0	26.2	26.2
Total for season		123	442.6	458.0	652.9	581.8	504.7
Grand total		298	1061.9	1143.7	1431.1	1241.2	-
Total for 1957-1958		223	819.1	878.9	1127.1	978.6	874.6

[4] H. L. Penman, "Estimating evaporation," Trans. Am. Geoph. Un. 37:43–46. 1956.

[5] C. H. M. van Bavel, "Estimating soil moisture conditions and time for irrigation with the evapotranspiration method," ARS 41-11, U. S. Dept. of Agric. 1956.

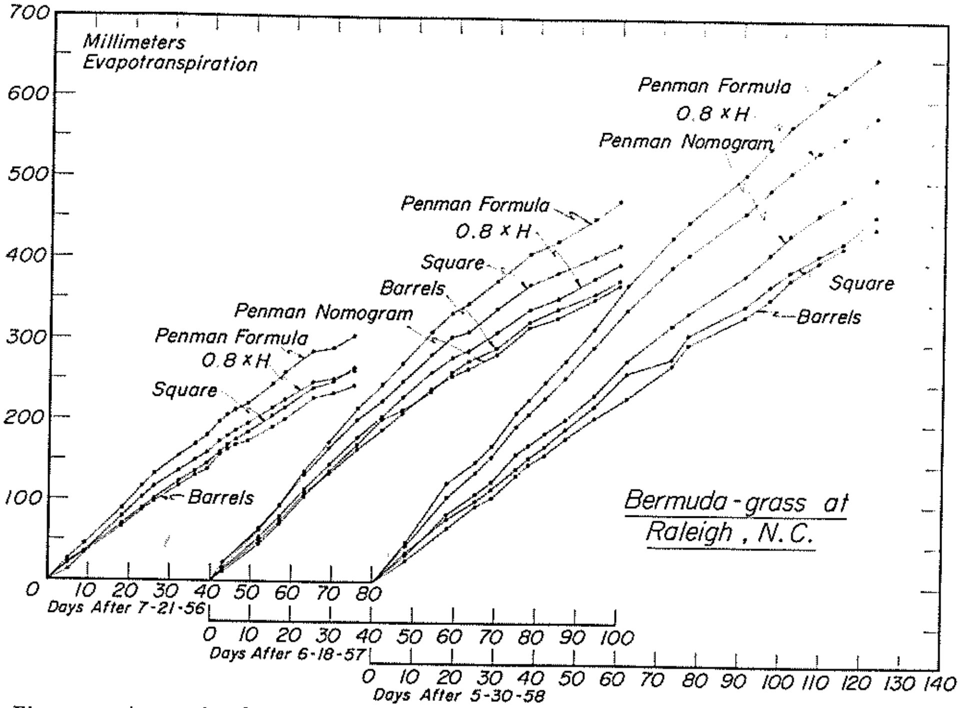

Figure 1—Accumulated evapotranspiration in mm. from bermudagrass at Raleigh, N. C., in 1956, 1957, and 1958, as measured in 2 types of percolation lysimeters ("barrels" and "square") and as computed by 3 methods ("Penman Formula", "0.8 × H", and "Penman Nomogram").

Table 3—Maximum evapotranspiration from corn for 22 periods during 2 growing seasons as measured by 1 method and estimated by 3 theoretical methods.

Period			Evapotranspiration, mm.			
No.	Start	Duration, days	Measured	Theoretical		
				~~Penman Formula~~ 0.8×H	~~0.8×H~~ Penman Nomogram	Penman ~~Nomogram~~ Formula
1	6/5 /57	6	18.0	16.8	12.7	
2	6/11/57	12	57.9	67.3	59.9	-
3	6/23/57	7	37.6	33.5	27.7	-
4	6/30/57	5	35.8	29.5	24.4	-
5	7/5 /57	4	36.6	24.9	21.6	-
6	7/9 /57	4	30.2	23.4	18.8	-
7	7/13/57	6	31.2	30.7	23.9	-
8	7/19/57	4	25.4	25.1	21.3	-
9	7/23/57	2	12.4	7.6	5.0	-
10	7/25/57	2	9.7	10.7	8.6	-
Total for season		52	294.8	269.5	223.9	-
11	6/9 /58	8	32.0	48.3	44.7	53.6
12	6/17/58	8	39.4	36.3	27.4	38.4
13	6/25/58	3	8.6	15.2	11.9	16.3
14	6/28/58	6	42.2	39.4	35.1	42.9
15	7/4 /58	3	15.2	15.2	10.9	16.3
16	7/7 /58	3	12.7	15.7	11.4	16.8
17	7/10/58	6	29.2	31.8	19.8	32.8
18	7/16/58	7	45.7	40.1	29.7	43.4
19	7/23/58	9	66.0	57.7	50.0	64.0
20	8/1 /58	11	71.6	58.7	45.2	65.8
21	8/12/58	6	16.0	27.4	19.3	29.7
22	8/18/58	11	51.3	48.5	35.6	54.4
Total for season		81	429.9	434.3	341.0	474.4
Grand total		133	724.7	703.8	564.9	-
23	8/29/58	7	22.6	39.6	32.8	43.4
24	9/5 /58	4	17.8	21.3	18.3	24.6
25	9/9 /58	7	15.2	27.7	25.7	31.8
26	9/16/58	6	9.7	20.8	19.0	24.6
27	9/22/58	9	5.3	32.0	26.2	37.6

was planted which matured by July 25, 1957. The observations were started when the plants averaged one foot in height and were continued up to the soft dough stage of maturity. In 1958, field corn was planted and data were taken in the same way. However, 5 additional periods totaling 33 days are listed in Table 3 showing the evapotranspiration rates after the corn reached the soft dough stage.

The data for the two seasons of corn are also illustrated in Figure 2 in which evapotranspiration is expressed as amount accumulated beginning with the first day of measurement.

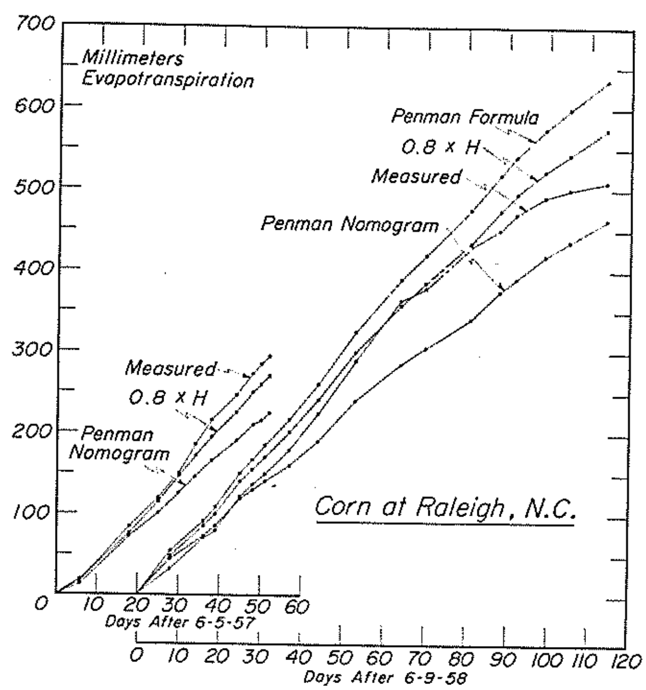

Figure 2—Accumulated evapotranspiration in mm. from corn at Raleigh, N. C., in 1957 and 1958, as measured in percolation lysimeters and as computed by 3 methods ("Penman Formula", "0.8 × H", and "Penman Nomogram").

ANALYSIS AND DISCUSSION

Table 2 and Figure 1 show that during 1958 there was no appreciable difference in evapotranspiration from bermudagrass between the square and the barrel type lysimeter.

Table 4—Correlation coefficients and regression equations relating actual observations to theoretical estimates of maximum evapotranspiration from bermudagrass and corn. Regression equations pertain to period totals.

Actual measurements (Y)	Theoretical estimates (X)	Degrees of freedom	Correl. coeff.	Regression equation
Bermudagrass	Penman Formula	50	.906	Y = 6.12 + 0.553 × mm.
Bermudagrass	0.8 × H	50	.886	Y = 6.58 + 0.619 × mm.
Bermudagrass	Penman Nomogram	33	.843	Y = 9.20 + 0.614 × mm.
Corn	Penman Formula	11	.933	Y = -7.11 + 1.090 × mm.
Corn	0.8 × H	21	.916	Y = 0.48 + 1.006 × mm.
Corn	Penman Nomogram	21	.883	Y = 4.77 + 1.097 × mm.

Both were treated alike and differed only in size and shape. During 1956 and 1957, the square lysimeters gave about 10% higher values than the barrel lysimeters. This is attributed to the fact that the square lysimeters with bermudagrass were irrigated every night, whereas the round ones, as well as the surrounding field, were irrigated only every six days or so.

Nonetheless, the behavior of the grass in the square lysimeters comparing 1958 with 1956–1957 is nearly the same, demonstrating that the character of the soil (rock screenings vs. fine sandy loam) had no perceptible influence upon the observed evapotranspiration.

Continuing an analysis of the bermudagrass data, we see that the 3 estimates of evapotranspiration bear the same relation to one another and to the observed data in each of the 3 years. The complete Penman formula persistently overestimates evaporation in all 3 years, but particularly in 1958. The simple 0.8 × H method gave good agreement in 1956 and 1957 as did the Penman Nomogram method. However, in 1958 both these methods provided estimates that were too high, particularly the 0.8 × H method. The summer of 1958 was characterized by numerous, often daily, small rainstorms, leaving the vegetation wet with intercepted rain much of the time. This condition is not reflected in any way in a straightforward application of the Penman formula or any method based thereon. Advective energy effects may also have played a role since the test area was not very large.

The above considerations deal with the over-all predictive aspects of the three computing methods for evapotranspiration rates. Another question is how well they may indicate the rates for short periods of time. Correlation coefficients and regression equations were computed pertaining to the relation between observed and computed amounts for each of the 51 periods involved. For this purpose the data of the 5 lysimeters in bermudagrass were combined, although a slight systematic difference occurred between the 2 types in 1956 and 1957, as noted above.

The results are shown in Table 4. Correlation coefficients are significant at the 1% level in all three cases. The use of actual net radiation measurements increases correlation between estimates and data appreciably compared to the use of sunshine percentage figures in the nomogram method.

The regression equations show that none of the estimates are very good for short periods. Evidently, in all cases low values of evapotranspiration are overestimated considerably and vice versa. The period-to-period variation of evapotranspiration rates as found experimentally is not reflected in these estimates, which are based mainly on conservative weather elements: radiation and average daily air temperature. Factors which may vary, such as soil heat storage or advective energy, are neglected in the estimates.

Table 3 and Figure 2 deal with the summarized data for corn. In this case the theoretical estimates were based upon the net radiation over the corn field and show a relationship similar to that in Figure 1. The 0.8 × H estimate comes close to the experimental data in both years, while the Penman Formula gives high values and the Penman Nomogram low values.

As in the case of the bermudagrass the evapotranspiration from the corn was lower in 1958 than in 1957, compared to the theoretical estimates. The effect of the wet season in 1958 was not as large with corn as it was with the bermudagrass.

Theoretical estimates of short-term evapotranspiration from corn are better correlated with actual observations than for grass. This is shown in Table 4. Also, the regression equations show that at least one estimate—0.8 × H—is quite good. Another point of interest—evident from Table 3—is that during the tasseling and silking and up to the soft dough stage the evapotranspiration from corn tended to exceed theoretical estimates. In 1957 this may be seen for the periods 6 through 9 (see Table 3) and in 1958 for the periods 18 through 22. Prior to the time of tasseling the corn did not form a complete land cover and after the soft dough stage the vitality of the plant as a whole declined.

In summary, it appears that the Penman method, either in its complete form or as some practical adaptation, going as far as using net radiation only, can provide reasonably accurate data on maximum evapotranspiration.

This statement applies to two morphologically very different crops—short grass and corn—but it is restricted to long-term seasonal values. For short-term prediction the Penman method is less accurate, tending to underestimate high values and overestimate low values of evapotranspiration.

In the use of the formula in our work no arbitrary factors of any kind or any modification that would apply only to local conditions were used. It is expected, therefore, that our conclusions can be applied widely.

Average daily rates of evapotranspiration for bermudagrass for the entire season were 3.45 mm. per day in 1956, 4.00 mm. in 1957, and 3.65 mm. in 1958. Maximum values observed were 5.28, 5.54 and 6.86 mm. per day in 1956, 1957, and 1958, respectively.

The average seasonal evapotranspiration rate for corn was 5.65 mm. per day in 1957 and 4.45 mm. per day in 1958. Maximum values, observed during pollination, were 9.15 mm. per day in 1957 and 7.33 mm. per day in 1958.

SUMMARY

During 1956, 1957, and 1958 maximum evapotranspiration was measured on bermudagrass and during 1957 and 1958 on corn. Measurements were made during the growing season in percolation type lysimeters. The lysimeters were located in test areas treated in a manner similar to the lysimeters themselves.

Evapotranspiration was also computed from pertinent weather data collected at the test site using Penman's formula and two simplifications thereof. Generally, all estimates used gave reasonable agreement with observations over long periods of time, the Penman formula in complete form tending to yield too high values. Over shorter periods of time—several days in length—estimates were less reliable.

Evapotranspiration rates from bermudagrass and corn do not differ materially but corn shows marked effects of stage of growth, as contrasted to grass.